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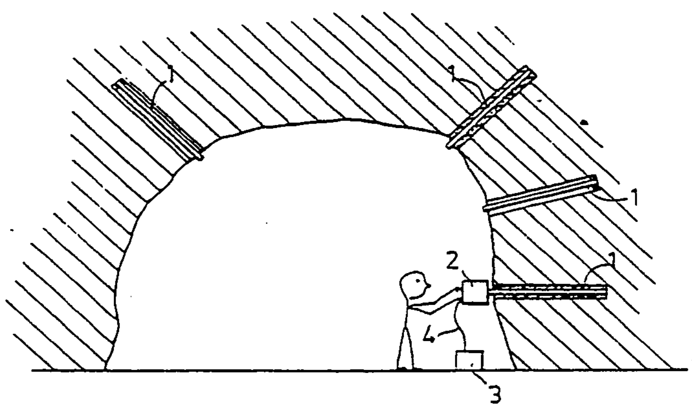
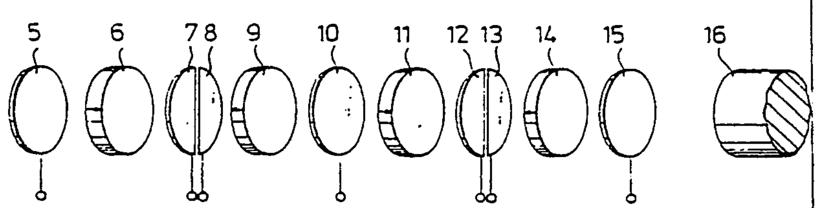
(54) **Title:** A METHOD FOR INVESTIGATING AN ANCHORED ROD-LIKE BODY HAVING AN ACCESSIBLE END, AND APPARATUS FOR CARRYING OUT THE METHOD

(57) **Abstract**

A method and apparatus for investigating a rod-like body (1, 61) which is anchored in a surrounding material (62) and which has an accessible end (16), for determining the state of the anchorage of the body and its length. Transient elastic oscillations are excitated in the accessible end of the body. The oscillations comprise a flexural wave causing a deformation of the body varying with respect to amplitude and phase over the cross-section of the body. The flexural wave propagates in the longitudinal direction of the body and is partially reflected at discontinuities of the body and/or the anchorage. Transient elastic oscillations comprising flexural waves reflected at such discontinuities and returning to the accessible end of the body are received and detected. The position and magnitude and/or type of at least some of the discontinuities are estimated with the aid of time-position and amplitude of the reflected flexural waves. Discontinuities of interest are the beginning and end of anchorage, the end of the body and possible cracks or fractures in the body and/or its anchorage. The method and the apparatus are primarily intended for in-situ investigation of concrete-bond (63) rock anchors (bolts), although the method and apparatus can be used for at least partially investigating other anchored rod-like bodies.





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A METHOD FOR INVESTIGATING AN ANCHORED ROD-LIKE BODY HAVING AN ACCESSIBLE END, AND APPARATUS FOR CARRYING OUT THE METHOD.

FIELD OF INVENTION

The present invention relates to a method of investigating an anchored rod-like body having an accessible end, and apparatus for carrying out the method. The method and apparatus are primarily intended for investigating the state of anchorage of the body and the length of the body and for determining the presence or absence of any substantial discontinuities therein or therealong, although the method and apparatus are not limited to such use, but can also be used for other investigations.

The method and apparatus are primarily intended for investigating concrete-bond bolts, although said method and apparatus are not limited heretofor but can be used, either completely or partially for investigating other anchored rod-like bodies, such as ground anchor rods, concrete-reinforcing rods and embedded pipe lines etc. By "concrete-bond" is meant that the bolt is anchored, e.g. in the wall or roof of a rock tunnel, by a concrete bond, either at one end or at one or more positions between the ends.

By state of the anchorage of the body is meant here the length of the bond or anchorage by which the body is fixed in the surrounding material and its localization along said body, and the extent of the contact of the body with said surrounding material. The state of the anchorage of the body, the length of the body and any other discontinuities therein all have an affect on the ability of the rod to take up or transmit loads.

By an accessible end of an anchored rod-like body is meant either a free end projecting a distance out of the anchorage or an end having at least the end surface free from the anchorage and accessible for direct mechanical contact with means

for generating and detecting transient elastic oscillations in the body.

BACKGROUND OF THE INVENTION

Conventional methods of mounting bolts, for example to strengthen the roof and walls of rock tunnels, do not in themselves offer a guarantee that the bolts are satisfactorily anchored in the rock. It is not possible to visually determine whether, for example, a concrete-bonded bolt has the prescribed length or that the bond is satisfactory, i.e. it has the desired load-carrying or load-transmitting abilities. Further it is possible for a bolt which was originally mounted correctly and which initially was in good contact with the surrounding rock and was sufficiently load-carrying, to subsequently become loose and at least loose a considerable part of its load-carrying ability. This may occur, for example, as a result of the bolt being subjected to shear forces or tension forces as a result of movement in the surrounding rock. If the bolt should fracture, it is impossible to detect the fracture visually, even though the fracture should occur att only a very short distance from the outer surface of the concrete-bond. There is thus a need for methods and means of checking the length and the function of bolts.

One method of checking the anchorage of a bolt and its load-carrying ability is to apply a tension force to the bolt, by means of a hydraulic jack for example, until the bolt fractures or loosens. Because of the costs involved and the amount of time required, normally only a small percentage of the total numer of bolts can be checked. Furthermore, the load-carrying ability of the bolts and the corrosion-protective effect of the concrete bond can be impaired by subjecting them to tensile tests, rendering the tested bolt underviceable, even though the bolt has not been pulled until it loosens or fractures. Furthermore, such tensile tests have a limited value, since it has been established that a bonding length of about 30 cm is sufficient to hold the bolt such as to cause the bolt to fracture when a tensile load is applied thereto. Thus, a tensile test

in which the end of the bolt fractures only shows that the bolt had a satisfactory bond length of at least approximately 30 cm.

The object of the present invention is to provide means in which the length of rod-like elements, such as rock bolts and the like, and the anchorage conditions thereof can be investigated in-situ without causing damage to said elements or impairing said anchorage. Thus, a rock bolt or like element subsequent to being tested shall be capable of being used for reinforcing purposes or for load-carrying purposes or for other purposes. By subjecting all, or a sufficient number of selected bolts within a given limeted area to such a non-destructive examination, it is possible to establish whether the reinforcement of a wall or a roof structure is sufficient, with respect to prescribed safety requirements. The non-destructive examination is made with the help of elastic oscillations.

It has long been known that elastic oscillations of a multiplicity of different wave types, can, under certain conditions, propagate along a circular-cylindrical homogenous body. Examples of such wave types include longitudinal waves, torsional waves, radial waves and flexural waves. When the oscillations have a sufficiently high frequency it is generally possible for more than one oscillation mode of respective wave types to propagate along the circular-cylindrical body. If, for the sake of simplicity, one limits oneself to the simplest oscillation mode of respective wave type and the lowest frequency thereof, it is relatively simple to describe the different wave types in a manner such that their difference are clearly apparent. The oscillation mode of the longitudinal wave is characterized by the fact that the entire cross section of the body is alternately compressed and expanded in the longitudinal direction thereof. The oscillation mode of the radial wave is characterized by the fact that the entire cross section of the body is alternately compressed and expanded in the radial direction. The oscillation mode of the torsion wave is characterized by the fact that adjacent cross sections of the body twist relative to each other around the axis of the body. The oscillation mode of the flexural wave is characterized by the fact that

certain parts of a cross-section of the body expand in the longitudinal direction thereof at the same time as other parts of said cross-section are compressed in the said longitudinal direction. The said parts are separated herewith by a diametrical, neutral plane located parallell with the sense of propagation of the oscillation mode, i.e. with the longitudinal axis of the circular-cylindrical body.

For a more exhaustive description of elastic waves in rod-like bodies, reference is made to the article "Elastic Waves in Rods and Clad Rods", by R.N. Thurston, published in the Journal of Acoustical Society of America, 64 (1), July 1978.

The propagation of waves through a concrete-bonded bolt is, for a number of reasons, more complicated to describe theoretically than the wave propagation in a circular-cylindrical homogenous free body. One reason, of course, is because the bolt is bonded in concrete and consequently not free. The contact of the concrete bond with the outer surfaces of the bolt causes certain restrictions to the possible compression and expansion of the cross-section of the bolt, at least in those parts of said cross-section lying closest to the said outer surface of the bolt. Another reason is that bolts do not normally have the form of a circular-cylindrical body. The majority of bolts today comprise reinforcing rods provided with a multiplicity of shoulders or teeth along their outer surfaces. The shoulders extend either tangentially at right angles to the longitudinal axis of the bolt, or at an oblique angle to said axis. Neither do the shoulders extend completely around the circumference of the bolt, but that certain bolts have peripheral portions which are not provided with such shoulders. In certain cases, the peripheral surface of the bolts may also be provided with one or two shoulders which extend in the longitudinal direction of the bolt. The result is that the cross-sectional shape of the bolt is neither circular nor constant therealong, but varies substantially periodically along the length of said bolt.

For a more exhaustive description of wave propagation in rod-like elements which may vary in cross-section along the length thereof, reference is made to the article "Wave Propagation in

Non-uniform Elastic Rods" by Gerald Rosenfeld and Joseph B Keller, published in the Journal of the Acoustical Society of America, volume 57, number 5, May 1975, pages 1094-1096.

SUMMARY OF THE INVENTION

The invention is based upon the concept of exciting transient elastic oscillations in the free end of a rod-like element which is anchored at one end thereof in a surrounding material. Such an oscillation propagates along the body and its anchorage at a speed and with a degree of damping which are dependent upon certain wave-propagation parameters. At discontinuities in the bolt and/or its anchorage and/or the material surrounding the bolt there occur reflected oscillations of a magnitude, type and direction which are dependent upon the geometric conditions and wave-propagation parameters, which are at least partially connected with the physical parameters of the bolt, the anchorage and the surroundings. By detecting such reflected transient elastic oscillations and interpreting and analysing the parameters of said oscillations, such as time of arrival, frequency, amplitude, mode etc., it is possible in accordance with the invention to obtain certain information about at least certain discontinuities.

Discontinuities which are of interest in respect of the ability of a concrete-bonded bolt to carry or transmit loads are primarily those located at the beginning and at the end of the bolt, the state of the concrete bond of the bolt, and possible cracks or fractures in the bolt and its anchorage. The contact of the concrete bond with the bolt and surrounding rock is also significant to the load-carrying or load-transmitting ability of the bolt. This contact influences the damping of the transient elastic oscillation and to a certain extent also its speed of propagation. By relating the amplitude of reflected oscillations to arrival-time and the amplitude of generated oscillations, it is thus possible to obtain indirectly some information concerning said contact.

The use of oscillations or vibratory movements for the non-destructive testing or checking of elements is, of course, not new per se. Material testing with the aid of ultrasonics and like methods has long been known. Testing in accordance with the present invention, however, differs from conventional ultrasonic testing, both with respect to excitation and detection and to the analysis of the oscillations.

The present invention is based on the concept of exciting and detecting transient transverse flexural waves, even in combination with longitudinal waves and/or torsion waves. It has namely been surprisingly found that the simplest, lowest-frequency oscillation mode of flexural waves is dampened to a much smaller extent when propagating in a concrete-bonded bolt made from reinforcing rod than, for example, the simplest, lowest-frequency oscillation mode of longitudinal waves of comparable frequency. Although, in accordance with the invention, it is mainly flexural waves which are excited, it is not possible, as a result of the anchorage of the bolt and the varying cross-sectional shape of said bolt, to exclude the fact that elastic oscillations of other wave types and/or oscillation modes are excited along the concrete-bonded bolt, at least at sufficiently high oscillation frequencies. Neither is it possible to fully exclude the fact that such elastic oscillations are coupled, in some way or another, to the original excited oscillation and propagated in conjunction therewith when the oscillation is of a certain frequency. It is possible, however, to completely or partially separate reflected oscillations of different wave types one from the other by suitable design of the means by which the reflected elastic oscillations are received. For a more exhaustive description of such excitation along a rod and said coupling, reference is made to the article "Experimental Study on the Wave Mode in Elastic Cylindrical Rod" by Toda Fukuoka Tanida, published in the bulletin of Japan Society of Mechanical Engineers, volume 19, number 132, June 1976, pages 590-594.

So that the invention will be more readily understood and further features thereof made apparent, exemplary embodiments of

the method and apparatus according to the invention will now be made with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 illustrates the investigation of a rock bolt fixed in the wall of a rock tunnel.

Figure 2 is an exploded view of means for exciting and detecting elastic flexural waves and longitudinal waves in a free end of a fixed, rod-like body.

Figure 3 is a block schematic of an apparatus for investigating a fixed, rod-like body.

Figure 4 is an exploded view of means for exciting and detecting elastic flexural waves and longitudinal waves, with the possibility of detecting flexural waves in two orthogonal directions in a free end of a fixed rod-like body.

Figure 5 is a block schematic of an apparatus for investigating a fixed rod-like body with the aid of excitation and detection means according to figure 4.

Figure 6 illustrates a multiplicity of bolts having bonds of different lengths.

Figures 7-15 show the configuration of the signals obtained when investigating rock bolts having bonds of mutually different lengths as shown in figure 6.

Figure 16 illustrates the configuration of a signal obtained when investigating a shorter bolt.

Figures 17-20 show circuit diagrams of embodiments of some of the blocks of figure 3 and figure 5.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In figure 1 there is illustrated a tunnel which has been formed in rock for example. Mounted in the roof and walls of the tunnel is a plurality of so-called rock bolts 1, each of said bolt having an end which projects freely into the tunnel. Some of the bolts my be free bolts, i.e. bolts that are anchored only at the bottom of the bore hole while others are anchored in

the rock by means of concrete bonds. When investigating a concrete-bonded bolt, a hand tool 2 is pressed against the free end of the bolt, said free end having been made flat or smooth prior to the investigation. The hand tool comprises one part of a two-part device for investigating the status of the bolt and comprises means for exciting and detecting given transient elastic oscillations in the outwardly projecting free end of the bolt. The hand tool and the said second part 3 of the device are connected together by means of an electric cable 4.

The transient elastic oscillations excited in the free end of the bolt propagate in the longitudinal direction thereof and give rise to reflected elastic transient oscillations at the beginning of the concrete bond and at other discontinuities, such as the end of the concrete bond and the end of the bolt, and at possible fractures in the bolt. During their propagation along the bolt in the axial direction thereof, from and towards the free end of said bolt, the elastic oscillations are dampened to an extent which depends, inter alia, on the extent to which the concrete bond is in contact with the bolt and with the surrounding rock.

The wave propagation velocities and the damping of transient elastic waves can be determined by measuring free bolts and bonded bolts of known lengths and known cross-sectional dimensions and anchoring conditions. The amplitude and shape of reflected oscillations which occur with different types and sizes of discontinuities of such anchorages and bolts can also be determined by measuring a multiplicity of discontinuities of known type and size. The hand tool and the said second part of the testing device together contain means which set the time position and/or amplitude and, optionally, other parameters of the received transient elastic oscillations in relations to pre-determined wave propagation velocities and damping etc., and give certain information about those discontinuities of the bolts and their anchorages at which the received reflected oscillations have occurred. The information may be of a more or less sophisticated nature and may be presented by presentation

means on the hand tool or the said second part of the device, or may be stored on magnetic tapes or the like. The invention relates specifically to the selection of excited and received wave types and oscillation modes, the means for exciting and receiving these wave types, and the manner in which the signals are processed in the present context.

The purpose of Figure 1 is merely to illustrate the field of use and the use of the invention. In fact a complete hand tool 2 has not yet been designed. The mechanical construction and design of the hand tool is believed to be of subordinate importance except for the device which excites and receives the transient elastic oscillations and the suspension of said device in the hand tool. Generally the suspension should be such as to suppress the generation of reflected waves in the hand tool. This is believed to be achieved by at least partially embedding said device in rubber and/or other soft material such as soft foamed synthetic resins. Figure 2 is an exploded view of parts of an embodiment of said means for exciting and receiving compression waves and flexural waves.

As will be seen from fig 2, said means comprises four piezoelectric (lead-zirconium-titanate)crystals 6, 9, 11 and 14 each of which is a one piece, cylindrical structure with planar mutually prallel end surfaces. The crystals each have an outer diameter of 25 mm and a thickness of 2 mm. The piezo-electric crystals are polarized at right angles to the parallel end surfaces thereof, i.e. parallel with their respective symmetry axes.

The first two piezoelectric crystals 6 and 9 are arranged between two brass electrodes 5 and 10 of circular cross-section and having a thickness of 0.05 mm, in a manner such that the directions of polarization of the two crystals are opposite to one another. Arranged between the two crystals 6 and 9 are two semi-circular, thin metal electrodes 7 and 8. The two electrodes 7 and 8 are spaced apart such as to leave a narrow, electrically insulating gap therebetween.

In a similar manner to the crystals 6 and 9, the crystals 11 and 14 are arranged between two circular, thin metal electrodes 10 and 15. Two semi-circular electrodes 12 and 13 are arranged between the crystals 11 and 14 in a manner similar to the semi-circular electrodes 7 and 8.

The various crystal-parts and the electrodes are bonded together by means of a two-component epoxy-resin adhesive.

When exciting and receiving transient elastic oscillations, the means shown in Figure 2 is held, in the bonded state, in the hand tool with the electrode 15 urged against the accessible end of the bolt 16. This end of the bolt has previously been made flat and smooth, by cutting and grinding or in some other manner. The contact surface between the electrode and said end surface is conveniently provided with a small quantity of contact-medium, such as vaseline.

Excitation of oscillations is effected by commonly connecting the three whole electrodes 5, 10 and 15 to earth potential and by applying an electric voltage to the semi-circular electrodes 7 and 8. When alternating-voltage pulses of mutually the same amplitude and phase are applied to the semi-circular electrodes 7 and 8, the crystals 6 and 9 will attempt to move the whole electrodes 5 and 10 alternately towards and away from each other in a planar-parallel fashion, and in this way give rise to a longitudinal oscillation. If, on the other hand, alternating-voltage pulses of mutually the same amplitude but a phase difference of 180° are applied to the two semi-circular electrodes 7 and 8, the crystals 6 and 9 will attempt simultaneously to move the one halves of the electrodes 5 and 10 towards each other and the other halves of the electrodes 5 and 10 away from each other, and vice versa, and in this way give rise to a flexural mode of wave movement.

Detection of the oscillations is effected with the crystals 11 and 14 and the semi-circular electrodes 12 and 13. Because the detecting electrodes 12 and 14 and the excitation electrodes 7 and 8 are elctrically separated by the electrically insulating

crystal material, the receiving of waves and the excitation of waves can be carried out simultaneously.

Detection of the oscillations is effected by commonly connecting the three whole electrodes 5, 10 and 15 to earth potential. If the two piezo-electrical crystals 11 and 14 are subjected to a deforming force by a received oscillation, an electric charge is obtained on the electrodes 12 and 13. If, for the sake of simplicity, it is assumed that the capacitance between the electrodes and earth and the modulus of elasticity of the crystals is constant, there is obtained a voltage on the electrodes which is substantially proportional to the deformation.

Figure 3 is a block schematic illustrating a device for testing a rod-like body which is fastened or anchored in a surrounding material, by exciting and detecting transient elastic waves by the device shown in Figure 2. For reasons of simplicity the whole device of figure 2 is represented by a block given reference number 22 in Figure 3. The two inputs of block 22 represent the electric leads to semi-circular electrodes 7 and 8 respectively. The two outputs of block 22 represent the electric leads to semi-circular electrodes 12 and 13 respectively. Since electrodes 5, 10 and 15 are grounded during excitation and detection these are not shown in figure 3. In the Figure 3 embodiment a signal generator 18 generates, in dependence upon a control means 17, a pulse with comprises one or a few sinus periods of suitable frequency. In the case of concrete-bonded bolts made from reinforcement bars and having a diameter of about 25 mm, the frequency should be between 20 and 100 kHz. The output of the signal generator is connected to an inverter 20, a switching device 21 and an input of the excitation and detection device 22. The switching device 21 has two inputs, of which the second is connected to the output of the inverter 20. The output of the switching device 21 is connected to the other input of the excitation and detection device. The upper and lower inputs of the xcitation and detection device 22 are connected to semi-circular electrodes 7 and 8 respectively. When the switching device 21 is coupled in the specific manner, indi-

cated in Figure 3, alternating-voltage pulses of mutually the same amplitude and phase are applied to the inputs of the excitation and detection device 22, said pulses generating longitudinal oscillatory movements. When the switching device 21 is coupled in the other specific manner, alternating-voltage pulses of mutually the same amplitude but with a phase difference of 180° are applied to the inputs of the excitation and detection device, said pulses giving rise to oscillations of the flexural mode.

The electric leads of the electrodes 12 and 13 in the excitation and detection device 22 are coupled to a signal-processing line comprising an inverter 23, a bistable switching device 24, a summation device 25, a band-pass-filter 26 and an oscilloscope 19.

The voltage from the electrode 12 is applied to a summation device 25. The voltage from the electrode 13 is applied to an inverter 23 and to one input of the two-stage switch 24. The output of the switch 24 is connected to the other input of the summation device 25.

With the switch 24 in the position indicated in Figure 3, the output signal of the summation device will be proportional to the sum of the two voltages from the electrodes 12 and 13. When the switch 24 is in its other position, there is obtained instead an output signal which is proportional to the difference between the two voltages from the electrodes 12 and 13. By summing the voltages, the detection obtains maximum sensitivity for the lowest oscillation mode of longitudinal waves, while the influence of flexural waves is suppressed. If the difference is formed instead, detection will have its maximum sensitivity for the lowest oscillation mode of flexural waves, while the influence of longitudinal waves will be suppressed.

The switches 21 and 24 can be set synchronously with one another by the control unit 17, such that excitation and detection is effected either in respect of longitudinal oscillating modes or oscillations of the flexural wave mode.

At the same time the pass band of the band-pass-filter 26 may be re-set so that there is used a frequency range which is optimal for each wave mode.

In order to meet the best mode and enabling requirements Figures 17-20 show circuit diagrams of embodiments of some of the blocks of Figure 3 and Figure 5 although it is believed that one skilled in the art could easily manufacture all of the blocks of Figure 3 and Figure 5 from commonly available standard components.

Figure 17 shows a circuit diagram of the inverter 20 in Figure 3. The inverter is built with an operational amplifier of type Burr Brown 3584 and external components as shown in Figure 17.

Figure 18 shows a circuit diagram of inverter 23 in Figure 3. The inverter is built with an operational amplifier of type RCA 3140 and external components as shown in Figure 18.

Figure 19 shows a circuit diagram of the summation device 25 in Figure 3. The summation device is built with two operational amplifiers RCA 3140 and external components as shown in Figure 19.

Figure 20 shows a circuit diagram of a subtractor as used in Figure 5. The subtractor is built with an operational amplifier of type RCA 3140 and external components as shown in Figure 20.

The control means 17 consists of a switch to control the switching devices 21 and 24 and a button to trigger the signal generator 18.

The signal generator 18 is a KROHN-HITE Corporation FUNCTION GENERATOR 5300 A used in trig tone burst mode. The band-pass-filter 26 is a KROHN-HITE Corporation VARIABLE FILTER 3202 in band pass mode.

The flexural wave excited in a rod-like body is characterized by a movement around a neutral plane oriented parallel with the

propagation axis of the wave, i.e. the longitudinal axis of the bolt. At the moment of excitation, the neutral plane coincides with the gap between the two electrode halves 7 and 8, to which the excitation voltage is applied.

The fact that the orientation of the neutral plane may have changed subsequent to the flexural wave having travelled along the rod, being reflected at the end surface thereof or at other discontinuities, and returning to the outer, free end of the bolt against which the excitation and measuring device is placed cannot be excluded. This change in direction of the said plane may be due to inhomogenities in the bolt, deformations in the bolt or at the bolt surfaces, and to the conditions prevailing at the reflective surface or the end of the bolt (the inner end thereof).

In order to be able to detect reflected flexural waves in an optimum fashion, the axis of symmetry of the detecting electrodes should coincide with the neutral plane of the flexural wave. One method of achieving this is to design the excitation and detection device in a manner such that the detecting part thereof can be rotated relative to the excitation parts thereof. A more sophisticated solution is one in which the excitation and detection device is constructed in a manner such that it is able to detect flexural waves in any selected axis or in two axes which are at right angles to one another. Figure 4 illustrates an embodiment of an excitation and detection device which can achieve this.

The embodiment of Figure 4 is similar to the embodiment of the device shown in Figure 2, but with the essential difference that the measuring electrodes 12 and 13 are divided into four sectors 34, 35, 36 and 37, as shown, instead of two.

By means of the embodiment of four sectors 34, 35, 36 and 37 of the detection-electrodes of the excitation and detection device shown in Figure 4, and complementary signal-processing means as shown in Figure 5, it is possible to detect flexural waves in two orthogonal directions.

The illustrated device comprises four piezo-electric crystals 28, 31, 33 and 38 each of which is a one-piece cylindrical structure with planar-parallel end surfaces. The piezoelectric crystals are polarized at right angles to the said parallel end surfaces, i.e. parallell with the axis of symmetry.

The first two piezoelectric crystals 28 and 31 are arranged between two circular, thin metal electrodes 27 and 32 in a manner such that the directions of polarization of the piezo-electric crystals are mutually oppositely directed. Arranged between the two piezoelectric crystals 28 and 31 are two semi-circular, thin, metal electrodes 29 and 30 in a manner such that they do not meet at their diameters, but are separated by a narrow, electrically insulating gap.

The crystals 33 and 38 intended for detecting the wave are also arranged between two electrodes 32 and 39, in a manner such that the polarization directions of the crystals are opposite to one another.

Arranged between the two detection crystals are four sector-shaped metal electrodes 34, 35, 36 and 37, in a manner such as to be electrically insulated from one another.

Figure 5 is a block schematic of an apparatus for testing an anchored rod-like body by exciting and detecting transient elastic oscillations by means of the device shown in Figure 4. For reasons of simplicity the whole device of figure 4 is represented by a block given reference number 46. The block has two inputs representing the electric leads to semi-circular electrodes 29 and 30. The block 46 has four outputs representing the leads to sector-shaped electrodes 34, 35, 36 and 37. Since electrodes 27, 32 and 39 are grounded during exciting and detection of oscillations the electric leads to those electrodes are not indicated in Figure 5.

In Figure 5 a pulse generator 42 is arranged to generate one or more pulses of short duration in response to a control unit 41, the energy of which pulses is found substantially within

the frequency range suitable for the elastic oscillation. The output of the pulse generator is coupled to the input of a band-pass-filter 43. The pulses filtered by the filter are applied to an inverter 44, a switching device 45 and one of the inputs of the excitation and detection device 46. The other input of the switching device 45 is connected to the output of the inverter. The output of the switching device 45 is connected to the other input of the excitation and detection device. The upper and lower inputs of the excitation and detection device 46 are connected to semi-circular electrodes 29 and 30, respectively.

When the switching device 45 is set to the specific setting indicated in Figure 5, alternating voltage pulses of mutually the same amplitude and phase are applied to the excitation electrodes 29 and 30 of the excitation device 46, whereby longitudinal oscillations are generated. When the switching device 45 is set to the other specific setting, alternating current pulses of mutually the same amplitude but with 180° phase difference are applied to the excitation electrodes 29 and 30 of the excitation device 46, thereby giving rise to oscillations of the flexural wave mode.

The output lines 47, 48, 49 and 50 from the excitation and detection device 46 are each connected to a respective sector-shaped electrode 34, 35, 36 and 37, as shown in Figure 4.

In the following description it is assumed that the excitation and detection device is oriented in a manner such that its axis of symmetry is horizontal and the upper, right electrode 34 is connected to a line 47. The lower right electrode 35 is connected to a line 48. The lower left electrode 36 is connected to a line 49. The upper left electrode 37 is connected to a line 50.

A summation device 51 is connected to the lines 47 and 50 and in this way produces a signal which is proportional to the sum of the voltages obtained from the two upper electrodes. A summation device 52 is connected to the lines 48 and 49 and

in this way produces a signal which is proportional to the sum of the voltages from the two lower electrodes. A summation device 53 is connected to the lines 49 and 50 and in this way produces a signal which is proportional to the sum of the voltages obtained from the two left-hand electrodes. A summation device 54 is connected to the lines 47 and 48 and in this way produces a signal which is proportional to the sum of the voltages obtained from the two right-hand electrodes.

The output signals from the summation device 51 are applied to a further summation device 56 and to a subtractor 55. The output signals from the summation device 52 are also applied to a further summation device 56 and to a subtractor 55, whilst the output signals from the summation devices 53 and 54 are applied to a subtractor 57.

The output signals from the summation device 56 are the sum of the signals obtained from the four detecting electrodes and, in this way, are most sensitive to the longitudinal compression wave, whilst the influence of the flexural wave is suppressed.

The output signals from the subtractor 55 represents the difference between the summation signal from the two upper electrodes and the summation signals from the two lower electrodes. A maximum output signal is obtained for flexural waves having a horizontal neutral plane while flexural waves having a vertical neutral plane and longitudinal compression waves are suppressed.

The output signal from the subtractor 57 represents the difference between the signals obtained from the two right-hand electrodes and the signals from the two left-hand electrodes. A maximum output signal is obtained for flexural waves having a vertical neutral plane, while flexural waves having a horizontal neutral plane and longitudinal waves are suppressed.

The output signal obtained from the subtractor 55 is applied to a band-pass-filter 58. The signal from the other subtractor 57 is applied to a band-pass-filter 60. The output signal from the summation circuit 56 is applied to the band-pass-filter 59.

The possibility that further information concerning at least one further bonded part of a bolt could be obtained by also generating torsional waves and shear waves cannot be excluded. Simple tests in practice have shown, however, that difficulties exist in obtaining a satisfactory mechanical coupling between one flat end of a bolt and the means for generating and detecting torsional oscillations. Possibly satisfactory coupling could be obtained if the accessible end surface of the bolt had the form of two semi-elliptical planar surfaces at angles to each other and to the longitudinal direction of the bolt, instead of flat end-surfaces.

Figure 6 illustrates in cross section three bolts 61 made from reinforcement bar, of which two are shown to be concrete-bonded in bores 62 in granite, the concrete bond 63 of the bolt C being longer than the bond of the bolt B.

The bolt A has not been concrete-bonded and is taken as a reference. Means for suspendning bolt A without causing substantial reflections are not shown in Figure 6 for reasons of simplicity. The bolt B has a concrete bond of about 20 cm of length, while the bond of the bolt C is about 40 cm of length. All the bolts are made from reinforcement bars having a diameter of 25 mm. Each of the bolts has a length of 2250 mm.

The outer ends of the bolts have been cut at right angles to the axes of the bolts, and worked to a surface fineness such that good contact is obtained between the bolt and the excitation and detection means when said means is held pressed against the end of the bolt via a contact medium, which in this case is a grease. The inner ends of the bolts have been cut with bolt shears and have not been especially prepared.

Figures 7-15 illustrate signals obtained when investigating the bolts shown in Figure 6 with the excitation and detection device described with reference to Figure 2. The device of Figure 2 was held without casing in the hand of an examiner and was urged by him against the flat end of each bolt respectively so that substantially the whole surface of electrode

15 was in good mechanical contact with the end surface of respective bolt and the centers of electrode surface and flat bolt end surface substantially were coinciding. The remainder of the device was functionally equivalent with the embodiment illustrated in the block schematic of Figure 3.

The shape and form of the signals shown in Figures 7-9 were obtained on an oscilloscope 19 connected to the output of the bandpass filter 26 with the switching device 21 in a position such that both excitation electrodes 7 and 8 had applied thereto an alternating voltage pulse of mutually the same amplitude and phase. In a corresponding manner, the switching device 24 was set so that the sum of the signals from the two detecting electrodes 12 and 13 was applied to the filter 26. These settings give optimum excitation and detection for the longitudinal wave mode. The filter setting in question provided a passband having a lower limit frequency of 20 kHz and an upper limit frequency of 60 kHz. Excitation was effected with an alternating voltage pulse comprising one period of frequency 40 kHz and an amplitude of 20 volts.

Figure 7 illustrates the signal when investigating the non-bonded bolt A shown in Figure 6. It will be seen from the signal configuration that the amplitude of the signal which has been obtained in conjunction with the excitation pulse has been limited in the summation device 25. Subsequent to the decay of the excitation pulse, the signal has a very small amplitude, up to the moment when an oscillation reflected at the other end of the bolt is detected, and can be seen approximately centrally in Figure 7. The figure also illustrates a number of other detected oscillations which have been reflected more than once against the inner end of the bolt and therefore occur at a later point of time and more to the right in Figure 7.

With knowledge of the propagation velocity of the longitudinal compression wave, the time-axis of the signal can be converted to a distance axis graduated in centimeters. Figure 7 illustrates a signal over 2 ms, which has been detected on a

loose bolt (the bolt A shown in Figure 6) having a length of 225 cm. The propagation velocity of the compression wave in respect of the loose bolt has been experimentally determined to be about 5.1 km/s within the frequency band in question. As will be seen from Figure 7, the actual length of the 225 cm of the bolt coincides quite well with the length calculated from the signal, which length is obtained on the distance axis of the Figure during the registration of the reflected oscillation from the inner end of the bolt, shown in the centre of the figure. At the same time the low signal-amplitude from the termination of the excitation pulse to the aforementioned reflection from the bolt end indicates that no essential discontinuities are present along the bolt.

Figure 8 illustrates the signal obtained when investigating the bolt B shown in Figure 6, i.e. a bolt having a concrete bond of about 20 cm. The amplitude scale and time scale coincide with Figure 7. The excitation alternating voltage pulse comprised one period and had an amplitude of about 20 volts.

A distance axis has also been shown in Figure 8, this axis being calculated from the propagation velocity of the longitudinal compression wave in a loose bolt and within the frequency band in question. It will be noticed, however, that the instantaneous propagation velocity in concrete-bonded portions is lower than the propagation velocity of 5.1 km/s determined experimentally in respect of a loose bolt. In the case of the illustrated bolts having bonding lenghts of about 20 cm and 40 cm respectively the mean propagation velocity fell by about 1% for each dm of bonding length.

In Figure 8, the length of the bolt has been marked with a line on the distance axis beneath the excitation pulse reflected from the ends of respective bolts. In addition, a hatched area is shown on the distance axis, this hatched area corresponding to the position and length of the bond.

In Figure 8, the reflected oscillations from the end of the bolt are shown approximately centrally in the figure. The re-

flected oscillations have considerably smaller amplitude than the corresponding oscillations reflected in the loose bolt shown in Figure 7. On the other hand, the arrival time of the reflected signal from the end of the bolt in Figure 8 coincides quite well with the arrival time shown in Figure 7. Consequently, from the amplitude and arrival time of the reflected oscillations it is possible to draw the conclusion that the bolt is bonded along a part of its length. Immediately after the excitation pulse in Figure 8, there are found reflected oscillations which indicate discontinuities along the bolt. In this case the discontinuities comprise the concrete bond.

With a bonding length of about 40 cm, corresponding to the bolt C in Figure 6, there is obtained a signal configuration shown in Figure 9. It will be seen from Figure 9, that the reflected oscillation from the end of the bolt has a very small amplitude. The position of the concrete bond along the bolt and the length of said bond is shown by a hatched area in Figure 9. The inner end of the bolt is marked with a line at the distance 225 cm. A reflected oscillation immediately after the excitation pulse indicates the discontinuity formed by the beginning of the concrete bond.

The signals shown in Figures 10-12 have been obtained with the same settings of the switching devices as those used when excitating and measuring the signals shown in Figures 7-9. The excitation wave type is thus substantially a longitudinal compression wave. The signals shown in Figures 10-12, however, have been obtained with a different filter setting, namely a pass band having a lower limit frequency of 60 kHz and an upper limit frequency of 100 kHz. Figures 10-12 are reproduced with the same amplitude scale and distance scale. The time scale in Figures 10-12 has also been supplemented with a distance scale and shows the position of the concrete bond along the bolt and the length of said bond. Excitation was effected with an alternating voltage pulse comprising one period of frequency 80 kHz.

Figure 10 illustrates the signal configuration when measuring the loose bolt A shown in Figure 6. Furthest to the left of the figure is shown the pulse of limited amplitude originating from the excitation signal. Approximately centrally of Figure 10 there is shown the oscillation reflected from the inner end of the bolt. This oscillation in Figure 10 is of much longer duration than the corresponding oscillation shown in Figure 7. This may be caused by the excitation and detection device in Figure 2 having resonances within the frequency range 60-100 kHz.

Figure 11 illustrates the signal obtained when investigating the bolt B in Figure 6 having a bond length of about 20 cm. Due to the fact that the bolt has been concrete-bonded to about 20 cm, the amplitude of the oscillation reflected from the inner end of the bolt has decreased, although the arrival time is substantially unchanged compared with the conditions in Figure 10.

Finally, Figure 12 shows the signal obtained when measuring a bolt having a concrete bond of about 40 cm, i.e. the bolt C shown in Figure 6. The oscillation reflected from the free end of the bolt has been damped further, as a result of the longer concrete bond.

The signals shown in Figures 13-15 have been obtained with the switching device 21, Figure 3, in a position such that there is applied to each of the two excitation electrodes an alternating voltage pulse of mutually the same amplitude but with 180° phase difference. In a corresponding manner, the switching device 24 was set so that the difference between the signals from the two detection electrode-halves was applied to the filter 26. These settings of the detection devices provide for excitation- and detection-sensivity in respect of flexural waves, whilst the longitudinal wave is suppressed. The lower limit frequency of the band-pass filter was here 40 kHz and the upper limit frequency 80 kHz. The frequency of the alternating voltage pulse was about 60 kHz and its amplitude about 20 volts. The Figures 13-15 have the same time scale as the

Figures 7-12 but the distance scale differs considerably, due to the large difference in the propagation velocity of the longitudinal wave and flexural wave respectively. The propagation velocity for a flexural wave of this frequency in bolt A has been determined experimentally as being about 3.3 km/s. The propagation velocity in concrete-bonded parts of bolts of the type in question has been determined experimentally as being about 3 km/s.

The signal shown in Figure 13 was obtained when investigating the loose bolt A shown in Figure 6. The amplitude-limited pulse originating from the excitation is shown furthest to the left of the figure. In the case of a flexural wave, this pulse has a longer decay time than in the case of a longitudinal wave. Shown to the right of Figure 13 is the signal reflected from the end of the bolt. At the distance 160 cm, approximately centrally of Figure 13, there is shown a reflected signal of the longitudinal wave mode, reflected from the inner end of the bolt. This has occurred as a result of irregularities in the testing equipment such as asymmetries in the excitation and detection device, excentricity between the axes of the excitation and detection device and the bolt axis, and irregularities in the free end surface of the bolt.

Figure 14 shows the signal when examining the bolt B shown in Figure 6, which has been concrete-bonded to a length of about 20 cm. The characteristics of the excitation signal has been changed somewhat, due to the discontinuity created by the concrete bond. Compared with the conditions relating to the loose bolt in Figure 13, the signal reflected from the inner end of the bolt has only been relatively slightly damped, due to the 20cm long concrete bond. A smaller reflected signal is also found in Figure 14 approximately at the distance 160 cm, due to the fact that it has not been possible to suppress the longitudinal wave completely.

Figure 15 illustrates the signal obtained when investigating the bolt C shown in Figure 6, which is concrete-bonded to about 40 cm, with flexural waves. The flexural wave reflected

from the inner end of the bolt has a relatively large amplitude, despite the fact that the length of the bond is about 40 cm. Generally, the lowest oscillation mode of the flexural wave is damped much less per unit of length when propagating along a concrete-bonded bolt than the lowest oscillation mode of a longitudinal compression wave of the same frequency. By using flexural waves, it is therefore possible to examine bolts with much longer concrete bonds, than when solely longitudinal compression waves are used. On the other hand, under certain conditions the longitudinal compression wave of the lowest frequency is more suitable for determining the beginning of the concrete bond of a bolt having a free end projecting outwardly from the bond. By alternately exciting and detecting both wave types, it is therefore possible in certain cases to obtain better information about the bond than when merely using flexural waves. There are reasons to assume that the same also applies in the case of, for example, plastics-bonded bolts. In practice it can be problematic to observe the reflected signal from the beginning of the concrete bond, when the distance between the free end of the bolt and the beginning of the concrete bond is so short that signal reflections are obscured by the still decaying excitation signal. In order to be able to detect a reflection clearly from the beginning of the concrete bond, a distance means, for example, comprising a circular steel cylinder with flat end surfaces having the same diamter as the bolt, i.e. in this case a diameter of 25 mm, may be placed between the excitation and detection device and the free end of the bolt. The distance means 40 is shown only partially in Figure 4 for reasons of space. Their actual length may be much longer than illustrated, e.i. 5 to 20 cm when the waves have frequencies between 20 and 100 kHz.

For the purpose of illustrating the possibilities of the flexural wave, there is illustrated in Figure 16 a signal configuration obtained when measuring a 150 cm long bolt bonded in concrete along 120 cms of its length. The signal reflected from the end of the bolt is shown clearly in the centre of the figure.

By way of summary it will be seen from the Figures 7-15 that the length of the bonded bolt can be roughly determined with knowledge of the propagation velocity of the type of wave when used and the time of arrival of the signal reflected from the inner end of the bolt. When measuring primarily with a longitudinal wave of low frequency it is possible by special observation of the signal from the time the excitation pulse has decayed to the time when the signal reflected from the inner end of the bolt has arrived, to determine if there is a discontinuity along the bolt and, if so, the position of said discontinuity therealong or at least the position of the beginning of a discontinuity. Damping of the waves per unit of length in free parts of a bolt and in parts whose concrete bond is satisfactory can be determined experimentally. Having knowledge of this damping and a rough idea of the length of the bolt, it is possible to obtain a rough idea of the length-quality of the bond with the aid of the total damping of waves reflected from the inner end of the bolt.

The examples given above and the described tests are only concerned with concrete-bonded bolts. There are reasons, however, to assume that by using the method or apparatus according to the invention it is also possible to determine the length of expander bolts, the position of the expanding part of the bolt and, at least to a certain extent, the extent of the contact between the expander and the surrounding material. Neither can the use of the method and apparatus according to the invention with other bonded rod-like bodies be excluded.

In case of a pretensioned bolt with either an expander or a bonding at the inner end there are reasons to assume that by using the method or apparatus according to the invention it is furthermore possible to determine approximately the extent of the contact between the bearing plate at the outer end of the bolt and the material underneath the plate. The extent of contact depends on the tension in the bolt. Thus it may be possible to estimate the tension in the bolt.

It is believed that the optimum frequency band is related to

the diameter of the rod-like body. Accordingly it is believed that the optimum frequencies are higher when the diameter is smaller, and the optimum frequencies are lower when the diameter is larger.

It is believed that the wavelength of the flexural wave should be greater than the diameter of the rod-like body, preferably a couple of times greater than the diameter.

CLAIMS

1. A method for investigating a rod-like body which is anchored in a surrounding material and which has an accessible end, for determining the state of the anchorage of said body and its length by the excitation and detection of elastic oscillations in the accessible end of said body, said method comprising the excitation of a transient elastic oscillation which includes a flexural wave, thereby to cause deformation of the body, said deformation varying with respect to amplitude and phase over the cross-section of the body, and said wave propagating in the longitudinal direction of said body; detecting transient oscillations of the flexural wave mode reflected at discontinuities of the body and/or said anchorage, said flexural wave causing in said body a deformation which varies in amplitude and phase across the cross-section of the body; estimating the position and/or type and/or magnitude of said discontinuities with the aid of the time-position and amplitude of said reflected oscillations; and determining the said state of said anchorage and the length of said body with the aid of said estimated discontinuities.

2. A method according to claim 1, comprising also exciting and detecting at said accessible end of said body such transient elastic oscillations whose deforming effect does not have a phase position which varies across the cross section of the body; and assessing, primarily the location of the nearest part of the anchorage to said accessible end and/or the character of said anchorage, with the aid of the time-position and/or the amplitude of said oscillations received.

3. A method according to claim 1, for investigating a concrete-bonded bolt having a diameter of about 25 mm, wherein the reflected oscillation used to assess the position and/or type or magnitude of said discontinuities lies in the frequency range 20-100 kHz.

4. A method according to claim 2, wherein there is excited at certain instances substantially only an oscillation of said flexural wave mode, causing in said body a deformation which is variable with respect to amplitude and phase acress the cross section of the body, and in other instances substantially only an oscillation which causes in said body a deformation of constant phase across the cross section of the body.

5. A method according to claim 4, for investigating a concrete-bonded bolt, wherein there is used received transient elastic oscillation which causes in said bolt a deformation of constant phase across the cross section of the bolt which lies in the frequency range of 20-100 kHz.

6. A method according to claim 3, comprising the excitation of not more than a few periods at a time of the simplest and lowest-frequency oscillation mode of the flexural wave type.

7. An apparatus for investigating a rod-like body which is anchored in a surrounding material and has an accessible end, for determining the state of the anchorage of said body and the length thereof, by the excitation and detection of elastic oscillations in the accessible end of the body, characterized by means for exciting and detecting a transient elastic oscillation which includes a flexural wave, causing in said body a deformation which varies both in amplitude and phase over the cross section of the body, which wave is propagated in the longitudinal direction of of the anchored body; and by means for determining the time position and amplitude of transiens elastic oscillations of said flexural wave mode reflected at discontinuities of the body and/or said anchorage, said transient oscillations causing in said body a deformation which varies in amplitude and phase over the cross section of the body.

8. An apparatus according to claim 7, characterized in that the device for the excitation and detection of transient elastic oscillations is so constructed that it can also excite and

detect a transient elastic oscillation of a type which causes in said body a deformation whose phase does not vary over the cross section of the body; and in that the means for the excitation and detection of transient elastic oscillations and/or means for determining time position and/or amplitude of reflected transient elastic oscillations are arranged to separate different wave types of reflected transient elastic oscillations.

9. An apparatus according to claim 7 or claim 8, characterized in that the means for the excitation and detection of transient elastic oscillations comprises at least two electro-mechanical converters which are arranged to be brought in movement-transmitting relationship whith the free end of the body, either directly or via a movement-transmitting means or medium; that the apparatus also comprises electric circuits for generating and supplying separate excitation voltages to the electro-mechanical converters, and receiving circuits for receiving from the electro-mechanical converters such separate voltages as those which are generated by reflected transient oscillations.

10. An apparatus according to claim 9, characterized by two electro-mechanical converters in the form of piezo-electric crystals provided with electrodes, said crystals having mutually adjacent, substantially identical semicircular surfaces which together have a size and shape which substantially corresponds to the cross sectional area of the body and which are arranged to be brought into movement-transmitting relationship with a surface on the cross section of the accessible end of the rod.

11. An apparatus according to claim 10, charachterized by more than two electro-mechanical converters in the form of piezo-electric crystals provided with electrodes, which crystals each have a surface located adjacent a surface of another crystal, said surfaces together having a size and shape which substantially corresponds to the cross sectional area of the body and are arranged to be brought into movement-transmitting relationship with a surface on the cross section of the acces-

sible end of the rod.

12. An apparatus for determining the length of a rod-like body which is anchored in a surrounding material and has an accessible end by the excitation and detection of elastic oscillations in the accessible end of the body, characterized by means for exciting and detecting a transient elastic oscillation which includes a flexural wave, causing in said body a deformation which varies both in amplitude and phase over the cross section of the body, which wave is propagated in the longitudinal direction of the anchored body; and by means for determining the time position and amplitude of transient elastic oscillations of said flexural wave mode reflected at discontinuities of the body and/or said anchorage, said transient oscillations causing in said body a deformation which varies in amplitude and phase over the cross section of the body.

13. Menas for the excitation and detection of transient elastic oscillations of the flexural wave type in an accessible end of a rod-like body anchored in a surround material, said means comprising:

at least four circular-cylindrical electro-mechanical converters arranged in a manner such that their axes substantially coincide; at least three circular electrically conductive electrodes; two semi-circular excitation electrodes arranged side-by-side between a first and a second of the converters; and
two semi-circular detection electrodes arranged side-by-side between a third and a fourth of the converters;
a first of the circular electrodes being arranged adjacent the first converter on the side thereof opposite to the excitation electrodes, another of the circular electrodes being arranged between the second and the third converter, the third circular electrode being arranged adjacent the fourth converter on the side thereof opposite to the detection electrodes, and the electrodes and the converters being bonded together to form a substantially circular-cylindrical body.

14. Means for the excitation of transient elastic oscillations of the flexural wave type in an accessible end of a rod-like body which is anchored in a surrounding material and for detecting reflected elastic transient oscillations of the flexural wave type in a selective one or both of two mutually perpendicular directions and comprising:
at least for circular cylindrical electro-mechanical converters arranged in a manner such that their axes substantially coincide; at least three circular electrically conductive electrodes;
two semi-circular excitation electrodes arranged side-by-side in between a first an a second of the converters; and four quarter-circular detection electrodes arranged side-by-side between a third and a fourth of the converters; a first of the circular electrodes being arranged adjacent the first converter on the opposite side to the excitation electrodes, a further of the circular electrodes being arranged between the second and the third converter, the third circular electrode being arranged adjacent the fourth converter on the opposite side to the fourth detection electrode and the converters being bonded together to form a substantially circular-cylindrical body.

15. A method for determining the length of a rod-like body which is anchored in a surrounding material and which has an accessible end by the excitation and detection of elastic oscillations in the accessible end of said body, said method comprising the excitation of a transient elastic oscillation which includes a flexural wave, thereby to cause deformation of the body, said deformation varying with respect to amplitude and phase over the cross-section of the body, and said wave propagating in the longitudinal direction of said body; detecting transient oscillations of the flexural wave mode reflected at discontinuities of the body and/or said anchorage, said flexural wave causing in said body a deformation which varies in amplitude and phase across the cross-section of the body; estimating the position and/or type and/or magnitude of said discontinuities with the aid of the time-position and

amplitude of said reflected oscillations; and determining the length of said body with the aid of said estimated discontinuities.

Fig. 1

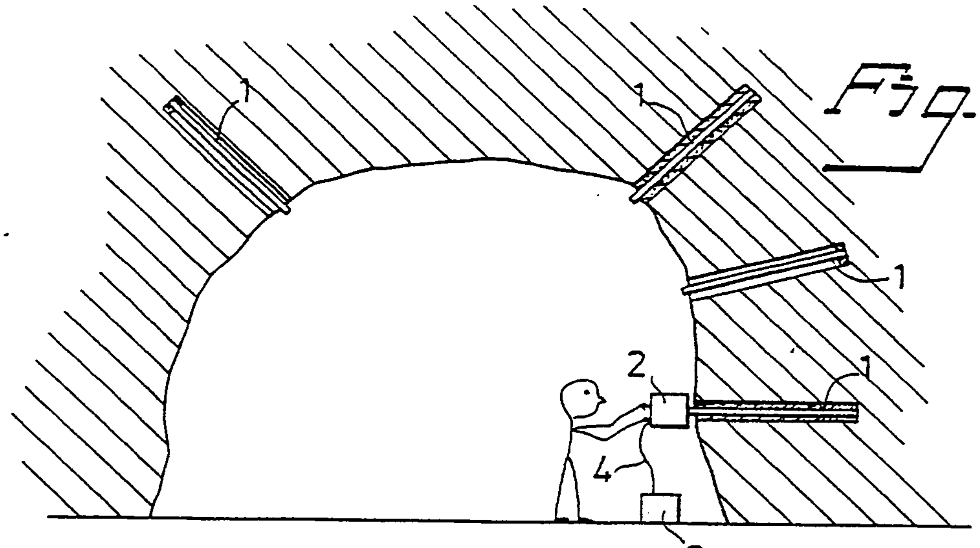


Fig. 2

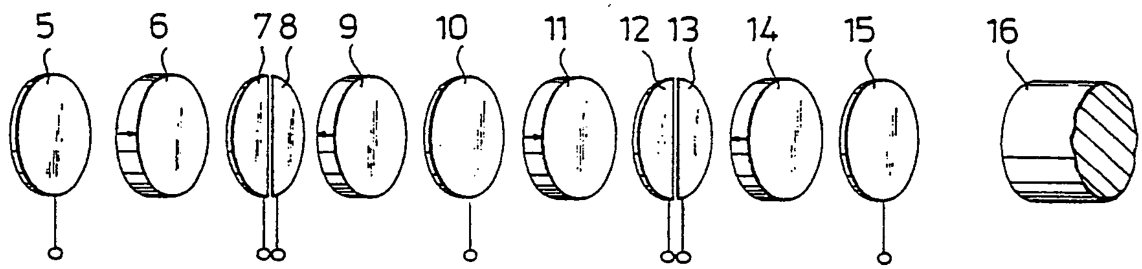


Fig. 3

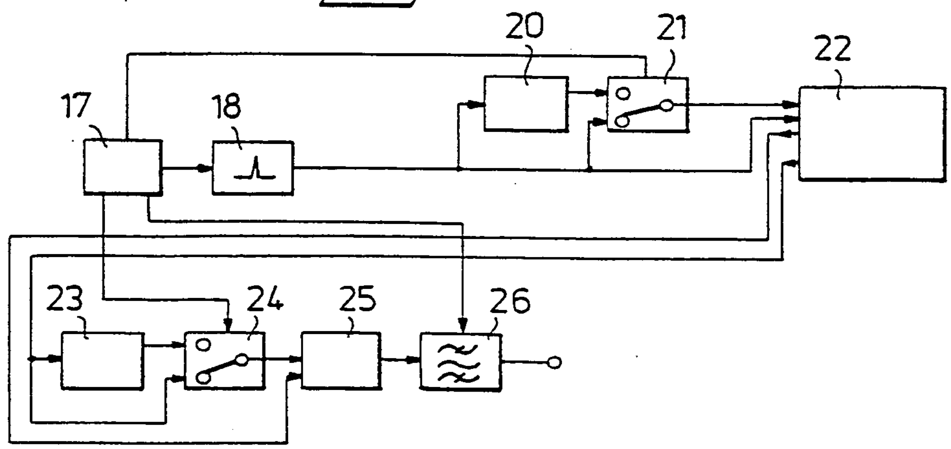


Fig. 4

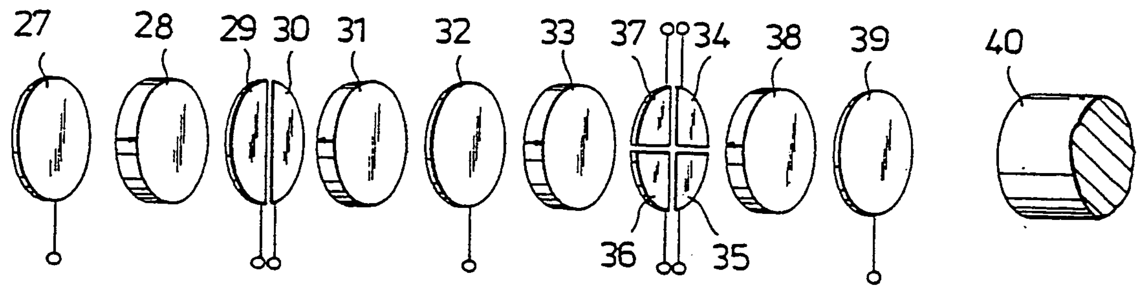


Fig. 5

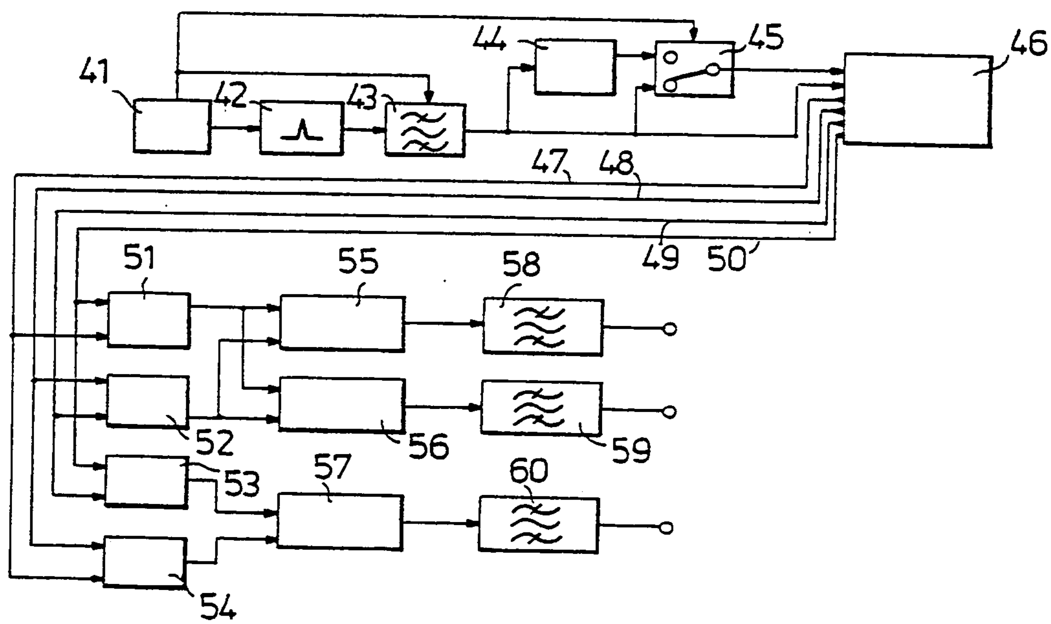


Fig. 6

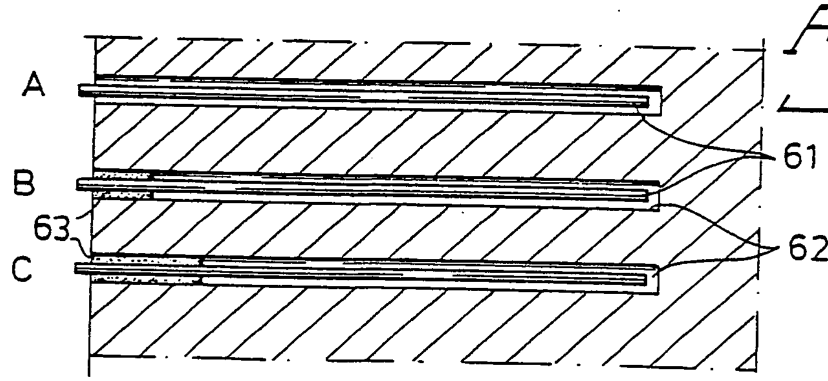


Fig. 7

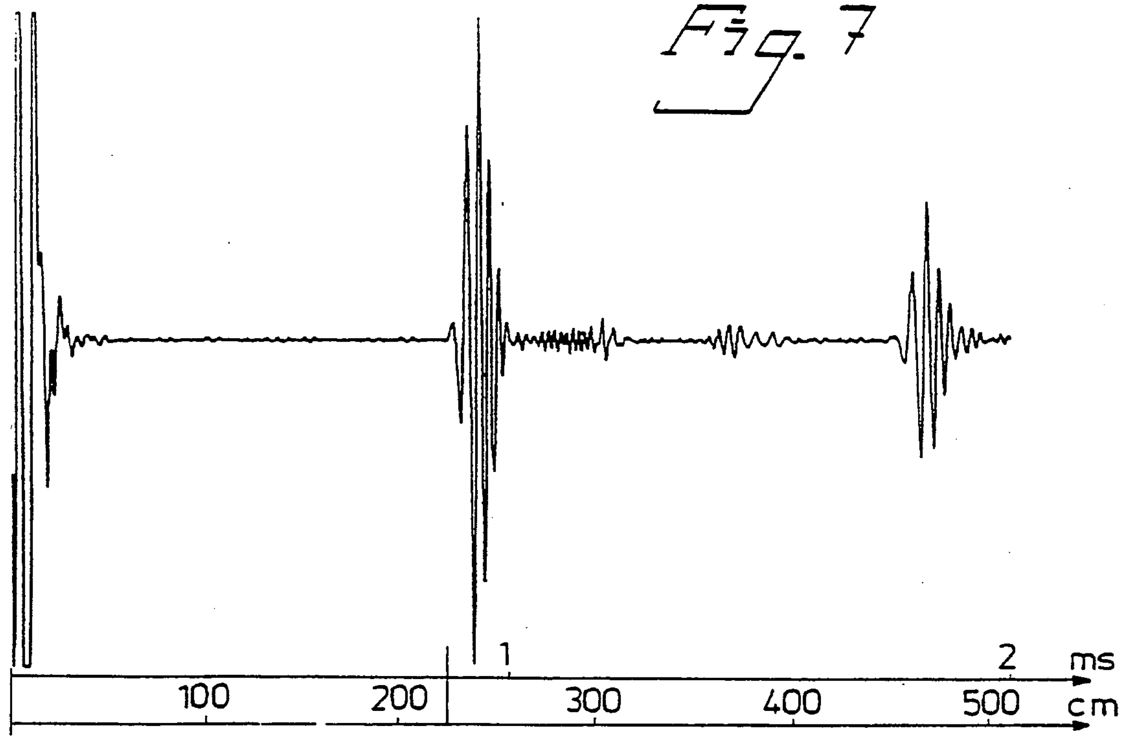


Fig. 8

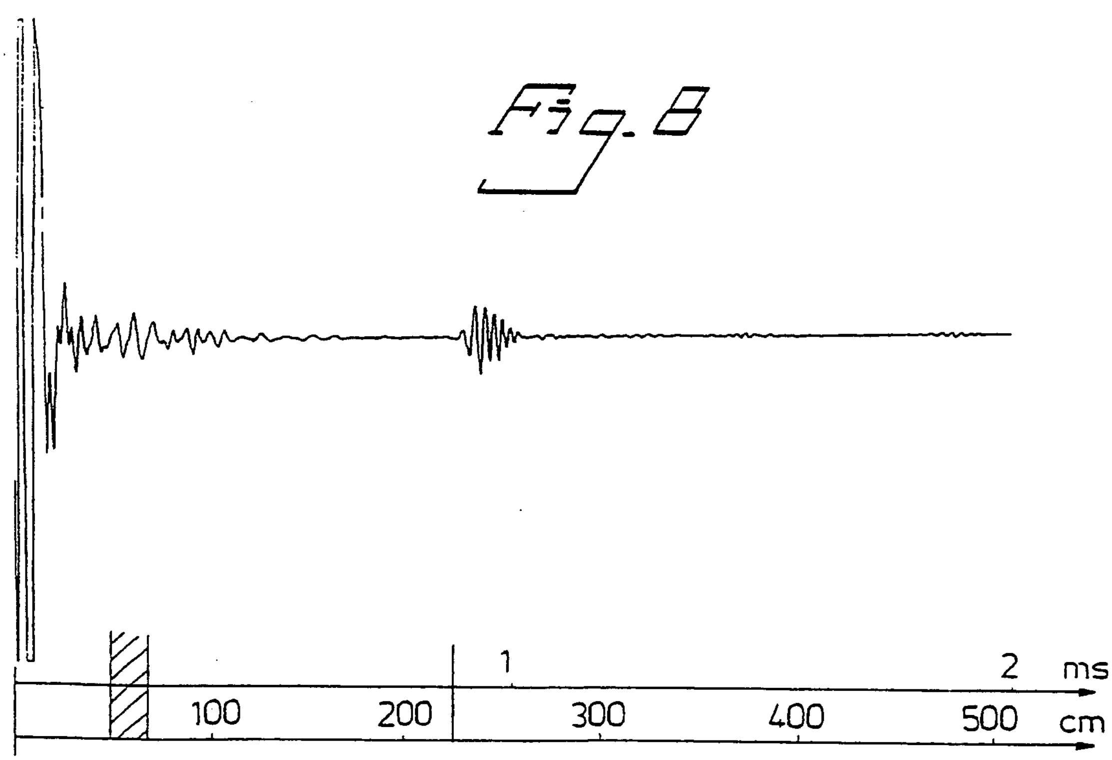


Fig. 9

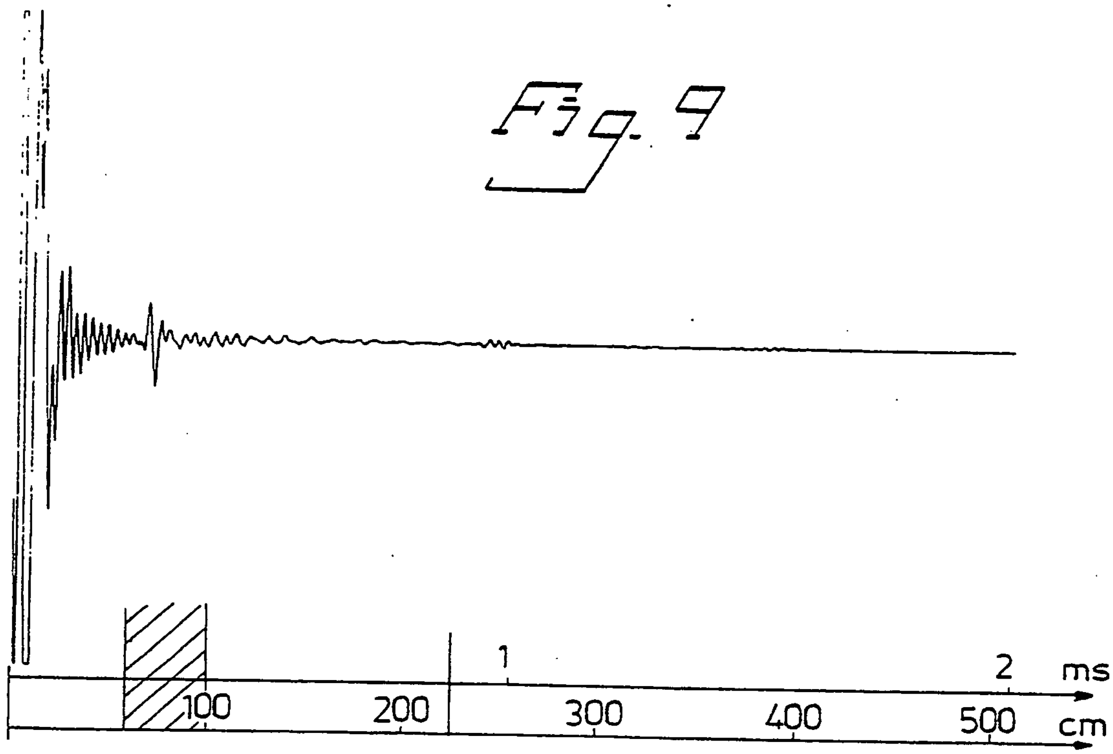


Fig. 10

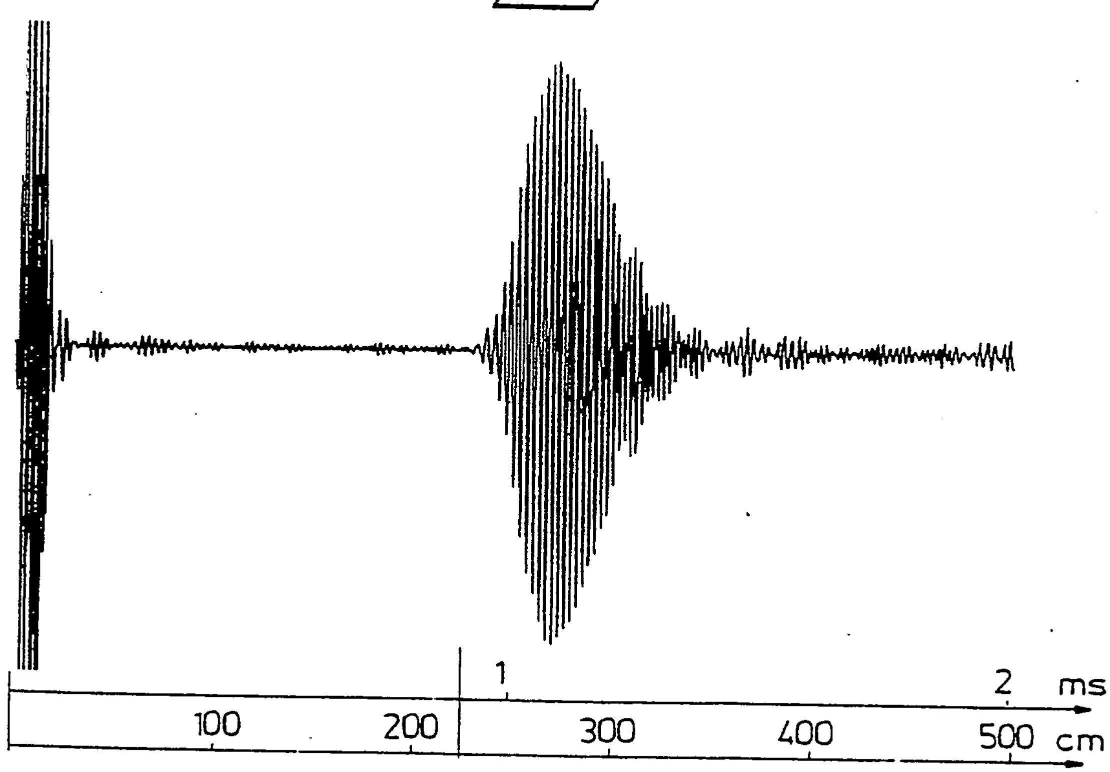


Fig. 11

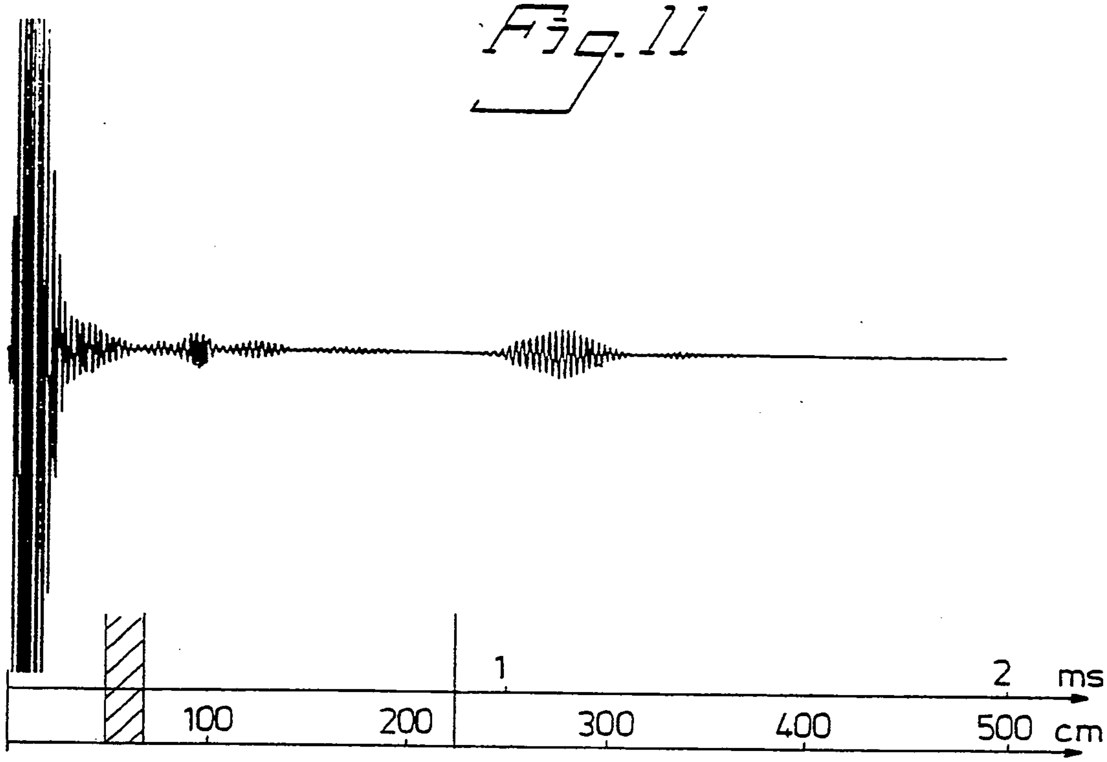


Fig. 12

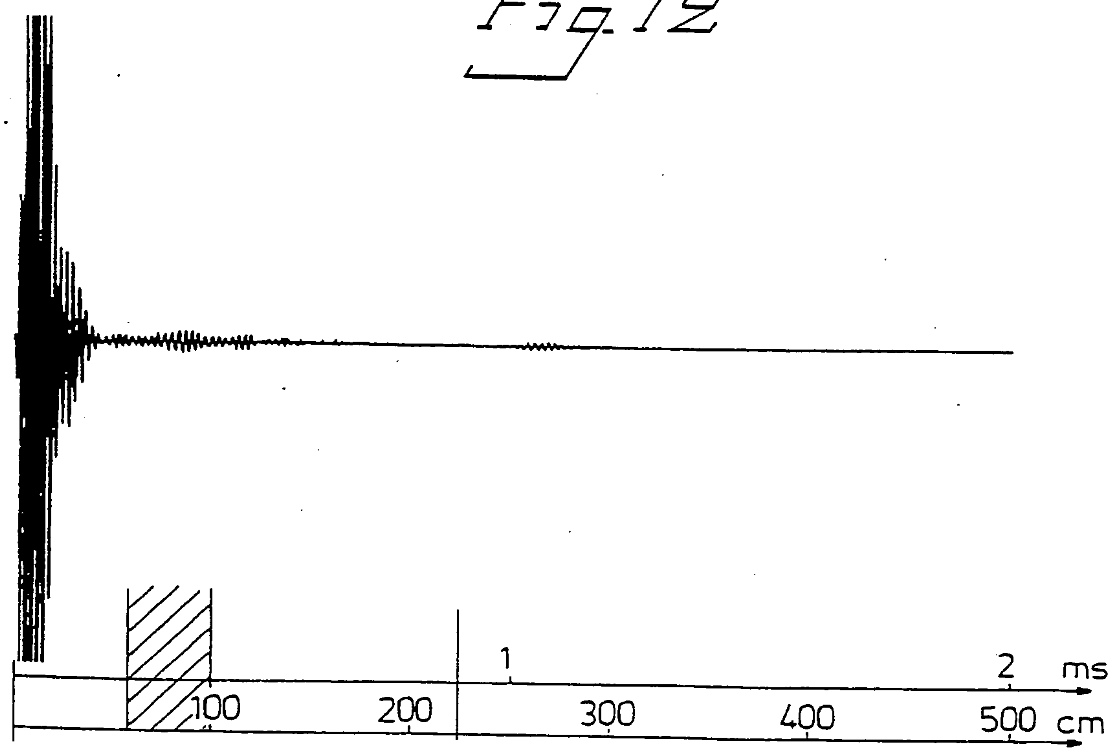


Fig. 13

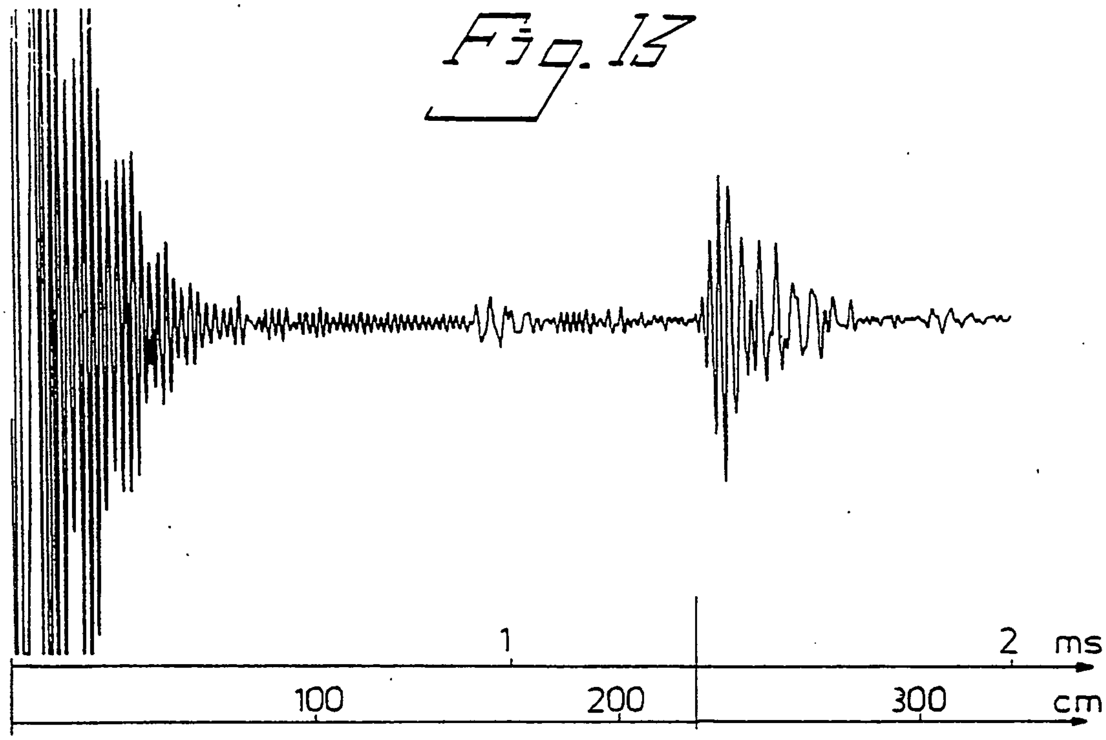


Fig. 14

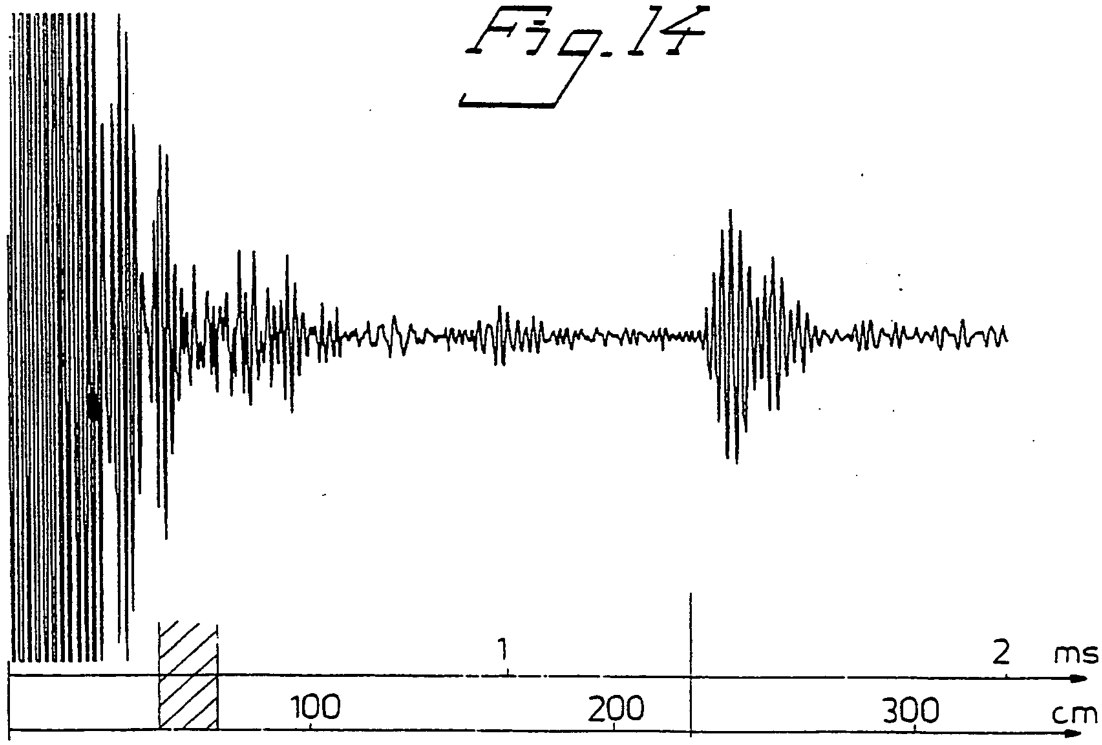


Fig. 15

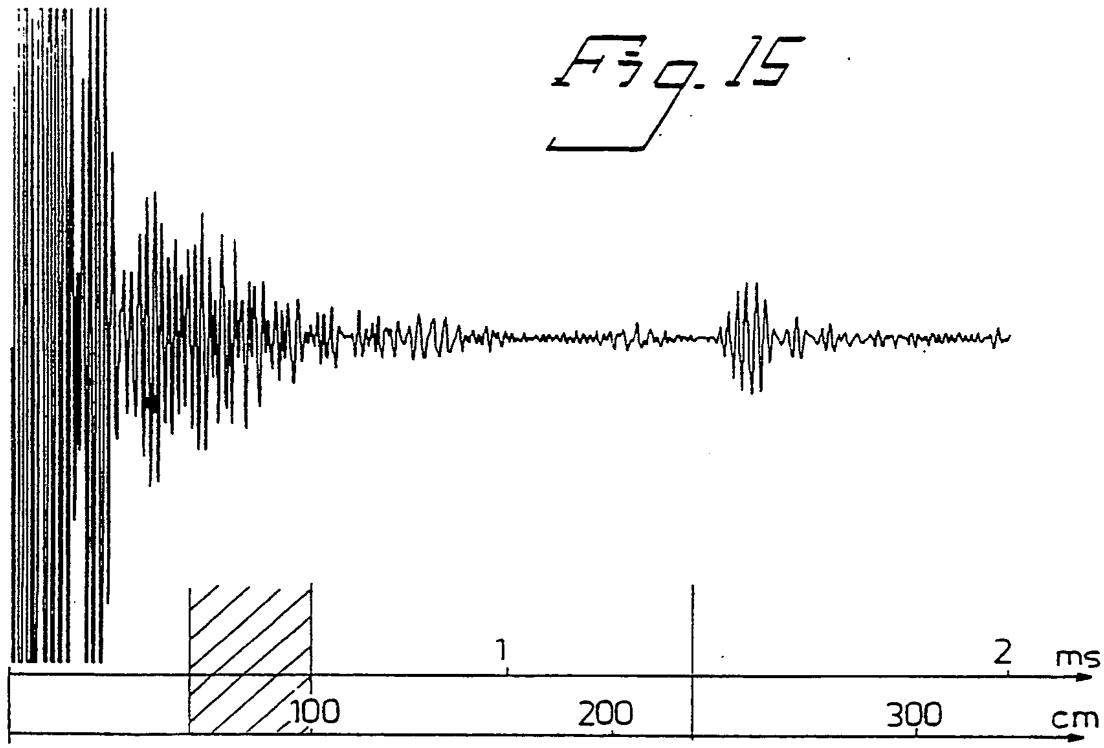


Fig. 16

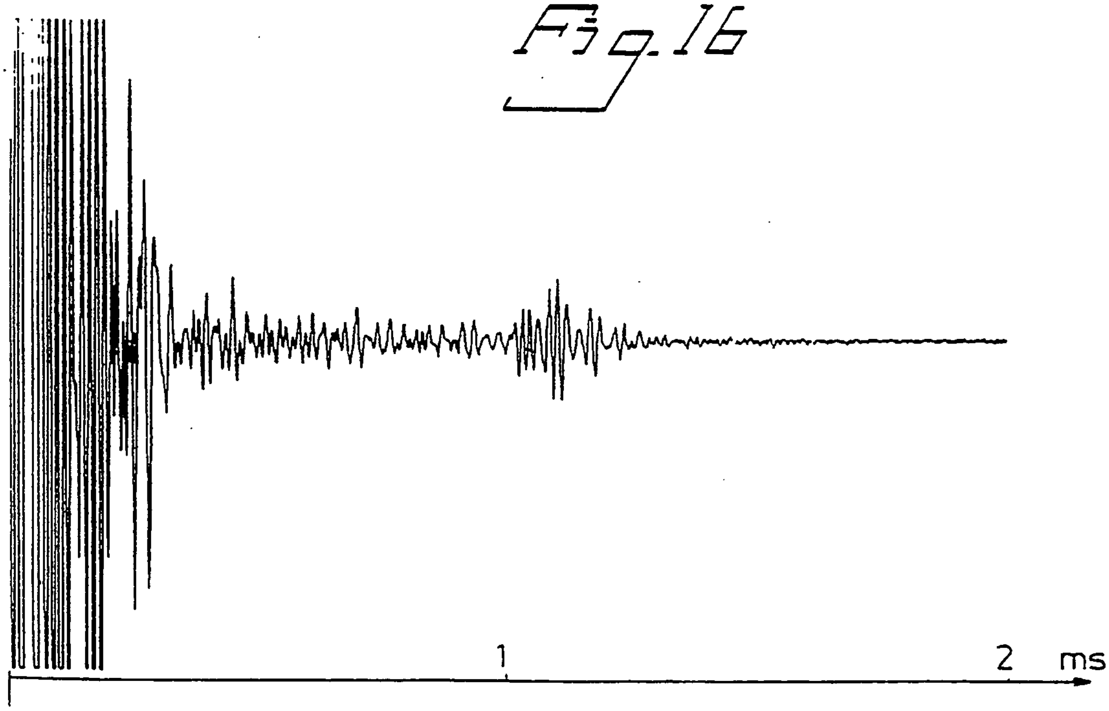
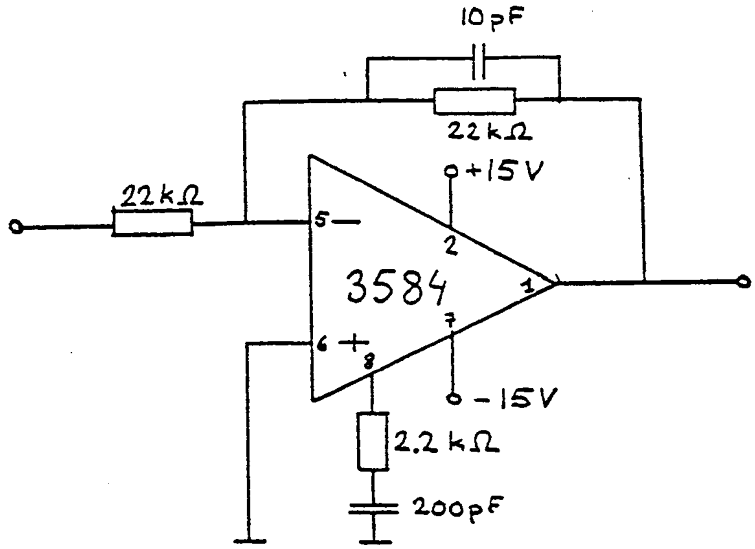


Fig. 17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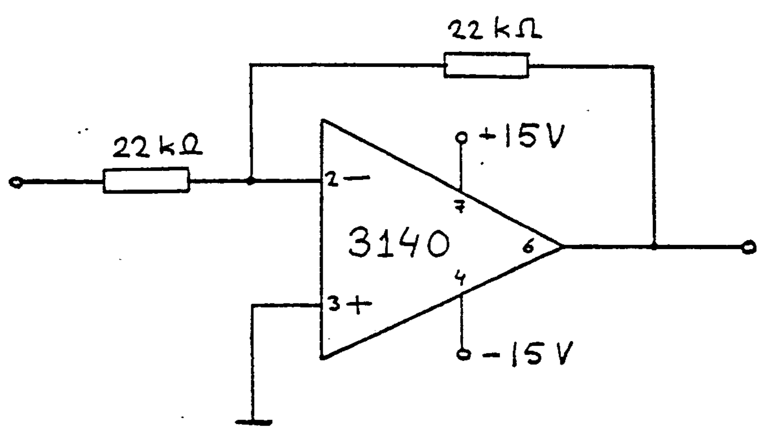
200pF

Fig. 18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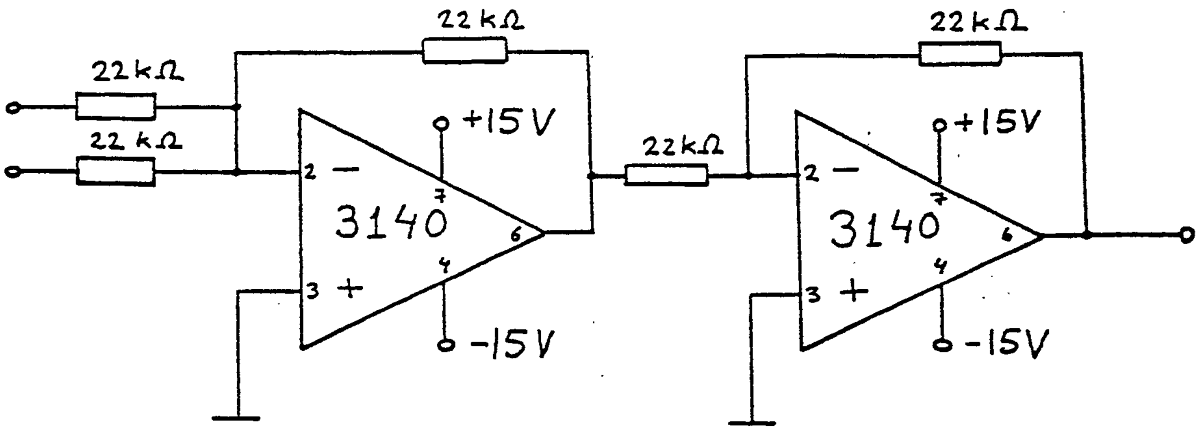
3 +
−15V

Fig. 19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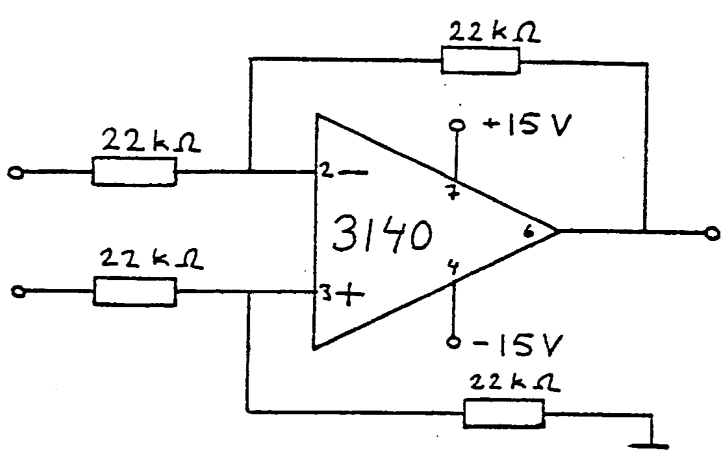
4
3 +
−15V

Fig. 20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WO 79/00929

INTERNATIONAL SEARCH REPORT

International Application No PCT/SE79/00092

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

G 01 N 29/04, G 01 S 9/66

WO 79/00929

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC 2	B 06 B 1/06; G 01 B 17/00; G 01 N 29/00, /04; G 01 S 9/66; /68; E 21 D 21/02
Deutsche Kl	42k:46/06

.../...

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
A	US, A, 3 066 525 published 1962, December 4, The Harris Transducer Corporation	
A	US, A, 4 014 208 published 1977, March 29, Rockwell International Corporation	
X	US, A, 3 593 255 published 1971, July 13, Marathon Oil Company	

* Special categories of cited documents: [15]

"A" document defining the general state of the art

"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
1979-07-26	1979-08-02
International Searching Authority [1]	**Signature of Authorized Officer [10]**
Swedish Patent Office	Göran Magnusson Göran Magnusson

International Application No. PCT/SE79/00092

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

II Continuation Fields Searched:

US Classification: 73-67, 67.2, 67.5, 67.6, 67.7, 67.8, 67.9, 69, 579, 588, 598, 340-1

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers ______, because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers ______, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.